

Structural Dynamics and Data Analysis

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I. Introduction

This summer I was given the opportunity to learn and work at NASA in the Dynamic Environments Branch of the Flight Analysis Division. My experience involved working with launch vehicles as well as the spacecraft to be flown on them.

II. Abstract

This project consists of two parts, the first will be the post-flight analysis of data from a Delta IV launch vehicle, and the second will be a Finite Element Analysis of a CubeSat. Shock and vibration data was collected on WGS-5 (Wideband Global SATCOM - 5) which was launched on a Delta IV launch vehicle. Using CAM (Calculation with Matrices) software, the data is to be plotted into Time History, Shock Response Spectrum, and SPL (Sound Pressure Level) curves. In this format the data is to be reviewed and compared to flight instrumentation data from previous flights of the same launch vehicle. This is done to ensure the current mission environments, such as shock, random vibration, and acoustics, are not out of family with existing flight experience. In family means the peaks on the SRS curve for WGS-5 are similar to the peaks from the previous flights and there are no major outliers. The curves from the data will then be compiled into a useful format so that it can be peer reviewed then presented before an engineering review board if required. Also, the reviewed data will be uploaded to the Engineering Review Board Information System (ERBIS) to archive.

The second part of this project is conducting Finite Element Analysis of a CubeSat. In 2010, Merritt Island High School partnered with NASA to design, build and launch a CubeSat. The team is now called StangSat in honor of their mascot, the mustang. Over the past few years, the StangSat team has built a satellite and has now been manifested for flight on a SpaceX Falcon 9 launch in 2014. To prepare for the final launch, a test flight was conducted in Mojave, California. StangSat was launched on a Prospector 18D, a high altitude rocket made by Garvey Spacecraft Corporation, along with their sister satellite CP9 built by California Polytechnic University. However, StangSat was damaged during an off nominal landing and this project will give beneficial insights into what loads the CubeSat experienced during the crash. During the year, the MIHS students generated a SolidWorks (CAD software) geometry model of StangSat. This model will be imported into FEMAP (Finite Element Analysis (FEA) Software) and a finite element model will be created to predict the loads encountered during the crash of this rocket. This analysis will require learning how to import CAD models into the FEM, mesh and add constraints and concentrated masses to represent components inside the CubeSat frame, such as circuit boards, batteries and accelerometers. During the analysis the loads will be varied, in effort to duplicate the damage to the CubeSat. Results will then be peer reviewed and documented.

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This summer I was given the opportunity to learn and work at NASA. I was able to immerse myself in the engineering world and find out what it is really like. I enjoyed this summer so much because I learned so much. I took the approach that I would be excited to learn about anything, even if I didn't think it would be interesting at first. All the people I met through this experience have taught me something different and have shown me that everything they do is interesting. This project consisted on two main parts. The first was a post-flight analysis of data from a Delta IV launch vehicle. The second was a Finite Element Analysis of a CubeSat.

In May of 2013, WGS-5 was launched on Delta 362 which was flying in the Medium+(5,4) configuration, 5 meter payload fairing and four solid rocket motors. Several channels of shock and vibration data were collected on WGS-5 using accelerometers mounted from the main engine to the payload attachment. NASA engineers use the data to monitor the launch vehicle and to build a database with nominal values, which can be used for troubleshooting if there is an off nominal flight. The data can also be used to update the environments used during testing of new components. To analyze the data, I used a software similar to MATLAB (MATrix LABoratory) named CAM (Calculation with Matrices). This program was developed by a NASA engineer to ease the process of analyzing data specifically for engineers working with loads and environments. In CAM, I edited the program's code to analyze the data from this Delta IV mission and to use previous flight data as a comparison. I used the software to compare WGS-5 to WGS-3 which was an identical launch vehicle and spacecraft. The data was plotted into Time History, SRS (Shock Response Spectrum) and SPL (Sound Pressure Level) curves for each event during flight, such as liftoff, engine shut down and stage separation. WGS-5 data was either below the levels of or in family with WGS-3 data throughout the flight. In family means the peaks on the SRS curve for WGS-5 are similar to the peaks from the previous flights and there are no major outliers. I then compiled the plots into a word document so that they could be peer reviewed.

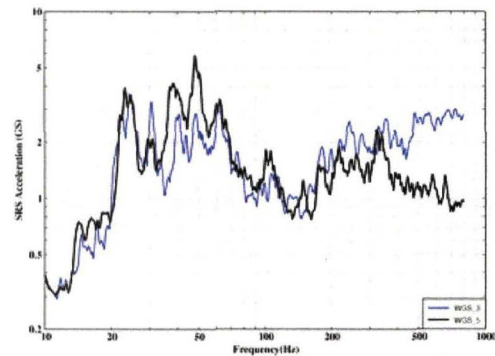


Figure 1. SRS curves in family. *This is an example plot to represent the definition of "in family."*

The engineer who wrote CAM in our group also taught me what PSD (Power Spectral Density) and SRS curves are, and how they are used here in the loads and environments section of NASA. This was especially helpful because it made my work real. I wasn't just typing things into the computer, I was creating a graph that would be used to verify the shocks and vibrations of launch were within limits. I also took a raw data file and learned how to read in the data and create a PSD and SRS curve line by line using CAM. This engineer also wrote a tutorial for CAM in which I learned how to write and manipulate matrices, write strings, and work with vectors. This was a great introduction into the world of matrices and gave me useful skills for when I work with MATLAB in the future. This will also help with several of the advanced math classes that I will take in college. I really enjoyed typing the lines of code into the program and seeing that the result was what I expected, or if it wasn't, figuring out how to fix it. It was a great moment when I was able to reason through a problem and fix it on my own to find the right answer.

The second part of this project was conducting Finite Element Analysis of a CubeSat. In 2010, Merritt Island High School partnered with NASA to design, build and launch a CubeSat. This is part of a pilot program named CUBES, Creating Understanding and Broadening Education through Satellites. I have been involved in this project for over a year. The CUBES program was designed to teach high school students how to build a satellite and how to go through the verification process. The team is now called StangSat in honor of Merritt Island High School's mascot, the mustang. The StangSat team is the first high school to work with NASA to build a CubeSat.

StangSat's mission is to collect shock and vibration data from accelerometers in our CubeSat. Currently the levels of shock and vibration are unknown for a CubeSat. Previous CubeSat builders have had to spend extra money and time testing their CubeSats to high levels because they don't have an exact environment. StangSat will provide this information along with their sister satellite, CP9. StangSat partnered with California Polytechnic University in this mission. CP9 sense liftoff and will turn on StangSat via an LED to phototransistor signal. StangSat will collect and send the shock and vibration data over WIFI to CP9. CP9 will also collect shock and vibration data within their CubeSat. Once we have been ejected from the rocket CP9 will downlink the data within the events of interest to their ground station in San Luis Obispo, California.

Earlier this year, the team applied through the ELaNa (Educational Launch of Nanosatellites) process to be on a rocket for the final mission. StangSat and CP9 are now manifested on a SpaceX Falcon 9 launch in 2014. To prepare for this final launch, the StangSat team traveled to California in June of 2013 for a test launch. This is an experience I will never forget. Prior to launch we completed integrated testing, which consisted of testing our LED to phototransistor signal and WIFI connection. Throughout testing the LED to phototransistor signal was functioning properly. However, the WIFI connection required a lot of troubleshooting. The combined CP9 and StangSat team learned through the week that we needed to

stop making changes during testing. This was an important lesson the teams will remember for future testing. In California, we would test something, it wouldn't work and then a change would be made and we would test again.

This turned out to be troublesome when we were half way through the series of tests. We had to decide if that change would invalidate all previous testing, or if the change would not have affected the previous tests. The night before integration, there were to be no more changes and we would test the two systems. The testing went well and we felt confident in our systems and that all would go well during launch.

StangSat and CP9 were launched on a test flight in Mojave, California on a Prospector 18D, a high altitude rocket made by Garvey Spacecraft Corporation. This flight was a proof of concept test to make sure StangSat and CP9 would work together during the final launch. Unfortunately, during the flight an off nominal event occurred, ending with the rocket crashing to the ground. This summer the second part of my project was to estimate the loads experienced during the crash landing. This insight would be beneficial for failure analysis. Over the past couple of years the Merritt Island High School students have generated a SolidWorks (CAD software) geometry model of StangSat. I imported this model into FEMAP (Finite Element Analysis (FEA) Software). FEMAP is an advanced engineering program used to accurately model components and determine their response to a certain environment. I learned how to mesh the model and add loads and constraints. I also ran tutorial models in which I analyzed buckling, created a solid model and meshed it, used post-processing, and did other analyses. I learned a lot from these tutorials, I was able to follow the steps and get the final result. It was very gratifying that I was able to use this software to create the model and analyze it.

Before this summer I had no experience with FEMAP. Unfortunately, due to issues with the way the CAD model was built, I was unable to convert it to a working finite element model. Without a working finite element model and having to overcome the learning curve of rebuilding it within a short time, I was unable to conduct the final analysis of StangSat. What I learned about the CAD model problems will be discussed with the StangSat structures team so that future models will run in FEMAP.

Since we returned from California, I have been working on my own and with the team to rebuild StangSat. We had spares of all of our parts, so we thought that we could put it together and program it and it would work just like the old one. However, it hasn't been that easy. One of my favorite days since California was when I was troubleshooting our CubeSat. It was just me and the CubeSat and I had to be the one to know what the readings meant and go through the process and do it right. There wasn't a mentor standing over me telling me what to do, while I had advice from them on what to test and how to go through it, it was me who did the test and made the decisions. I felt like a real engineer doing what I want to do for the rest of my life. While it was a few days later that we actually saw the development board functioning, the process of testing was fulfilling. That's why I think it wasn't always what I did this summer that made a difference; it was how I did it and the learning that went behind it.

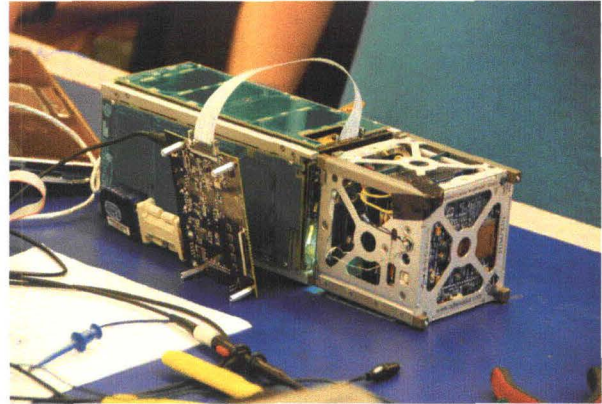


Figure 2. Integrated testing between StangSat and CP9. *StangSat is the CubeSat on the right, CP9 is the CubeSat on the left.*

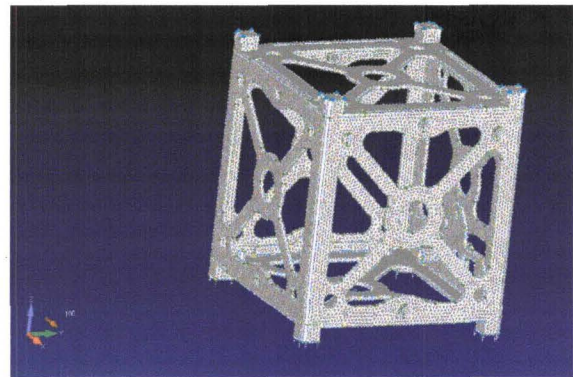


Figure 3. Model of StangSat in FEMAP. *This is the model that I loaded into FEMAP, meshed, constrained, and applied a 100 g load in the direction of the positive X axis.*

The StangSat team is still working to rebuild StangSat and have it functioning again. We need to have StangSat working for our upcoming EMI (ElectroMagnetic Interference) testing. This summer I have been involved in the preparations for this testing. This test will give us a characterization of the radio signals emitted by StangSat in its current configuration. It will give us documentation for when we are getting ready to fly on the SpaceX Falcon 9, we can show exactly what frequencies and power levels we are sending out and how it will affect, or hopefully not affect the launch vehicle and main payload. We would like to be within the EMI limits set by SpaceX, but because we are intentionally transmitting during flight our WIFI module is a major EMI source. This is unique for a CubeSat, which typically are not even allowed to turn on until 40 minutes after they are released in flight. If we are not within the required limits, we need to find out how to improve our system to eliminate any possible problems for the launch vehicle or primary payload. The EMI team has been very helpful in preparing for this test, and they even plan to help us solve problems that may come up in the future. Being involved in this stage of the StangSat project has been a great learning experience. Before we started talking about EMI testing, I didn't know much more than what EMI stood for. I have now learned the importance of EMI testing and how to work toward emitting within limits. I now know that we send out radio signals just by having a clock in our CubeSat. I enjoy every meeting we have with the EMI experts; I learn something new about the testing process and how EMI affects our everyday lives.

This summer was such a great learning experience and I think it will make me a better engineer in the future. I feel that it has equipped me with skills and knowledge that can only be gained with hands-on experience. I am so thankful for this opportunity that will stay with me throughout my career. I feel truly inspired to become an engineer and feel as if I am following the right path in my life.

Acknowledgments

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